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SPACE AND WEAPON SYSTEMS

TECHNICAL REPORT

DEVELOPMENT AND QUALIFICATION TESTS OF THE RA-3 AND RA-4 SPIN MOTORS (TEST PLAN B-2, ACCEPTANCE C-4 TEST PLAN B-29, ACCEPTANCE C-26)

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Pasadena, California

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6 July 1962

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SECTION 1

FOREWORD

This report covers the qualification of the RA-3 and RA-4 Lunar Capsule spin motor. Qualification tests of the RA-3 motor are in accordance with Test Plan B-2 and Acceptance C-4. Qualification of the RA-4 motor followed an engineering product improvement effort and is in accordance with Test Plan B-29 and Acceptance C-26.

Because of the compressed schedule on which this work was done, the test programs tend to merge and to resemble a development effort. As a result, although a total of only 24 tests were scheduled for qualification of RA-3 and RA-4 spin motors, about 40 firings have been made since the start of RA-3 qualification. Data from 34 of these tests are directly applicable in prediction of flight motor performance and are included in this report.

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SECTION 2

CONCLUSIONS

Qualification tests of the spin motor are completed. Significant performance characteristics, total impulse, burning time, and torque vector alinement are well within system requirements. No failures or indications of failure have been observed. The spin motor is considered qualified for flight.

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SECTION 3

SUMMARY

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3.1 RA-3 QUALIFICATION, TEST PLAN B-2

A total of 17 spin motors were fired to qualify the basic design configuration of the RA-3 motor. (These runs, 104 through 182, are shown in Table V.) Minor design changes were made during the qualification program. These changes did not affect the basic performance of the motor but did improve the spurious torque characteristics. Of the total, 5 motors of the final flight configuration were tested; spurious torque information is based on these. For other characteristics, including primary torque impulse, specific impulse, burn time, and reliability, all firings which simulate flight conditions are considered. Significant data are summarized in Table I. Test runs used in determining the values of the various parameters are listed and explained in Table VI.

TABLE I

RA-3 SPIN MOTOR QUALIFICATION TEST DATA

Parameter	Number of Data Points	Minimum	Maximum	Average
Tip-off angle orthogonal vector (rad)	5	0.0048	0.0185	0.0110
Cross axis velocity (fp	5	43	165	98
Specific impulse (sec)	12	166	203	179
Burn time to 5 percent torque (sec)	13	1.25	1.44	1.34
Capsule roll rate (rad/sec)	13	24.25	30.39	26.85

3.2 RA-4 QUALIFICATION, TEST PLAN B-29

A total of 18 spin motors of substantially the flight configuration of the RA-4 motor were fired during the design and qualification programs. These are runs 214, 218, and 230 through 274. Of these, 4 were fired in the gas dynamic fixture, and 14 in the torque fixture. A second arbitrary division separates the tests into 13 qualification firings and 5 experimental firings.

Of the total number of motors fired, 7 motors of exactly the flight configuration were tested on the torque fixture from which the motor spurious torque characteristics can be isolated. On gas dynamic fixture tests, the effective tip-off angle is partially dependent on other effects; therefore, these results are tabulated separately. Two of the qualification firings and the experimental motors differed in minor detail from the flight motors, as are described later in this report. For the other performance characteristics, all firings and significant data are summarized in Table II. Test runs used in determining the values of the various parameters are listed and explained in Table VII.

TABLE II

RA-4 SPIN MOTOR QUALIFICATION TEST DATA

Parameter	Test Condition	Number of Data Points	Minimum	Maximum	Average
Tip-off angle orthogonal vector (rad)	Spin motor only in torque fixture Nozzle Tool No. 1	6	0.0012	0.0080	0.0048
Cross axis velocity (fps)		6	11	71	43
Tip-off angle orthogonal vector (rad)	Gas dynamic fixture w/o spin restraint	2	0.0040	0.0109	0.0075
Cross axis velocity		2	36	97	67
Tip-off angle orthogonal vector (rad)	Gas dynamic fixture with spin restraint	3	0.0017	0.0047	0.0032
Cross axis velocity (fps)		3	15	42	29
Specific impulse (sec)	All motors conditioned at vacuum and constant temp for 66 hours or more.	12	204	210	208
Burn time to 5% torque (sec)		12	1.10	1.19	1.14
Capsule roll rate (rad/sec)		12	31.89	33.75	32.79

SECTION 4

TEST PROCEDURE

4.1 ENVIRONMENTAL PRE-CONDITIONING

The qualification tests followed the procedure specified in Test Plans B-2 and B-29. Some modifications in preconditioning of the motors were made as the test program progressed. The precise preconditioning received by each of the motors is shown in Table III.

To simplify the testing program, a portion of the grain qualification was accomplished in the igniter qualification program, which was run concurrently. The igniter grain sets were used to qualify the motor for exposure to formalin as used for sterilization in motor assembly and ethylene oxide as used in the final spacecraft sterilization. Detailed information concerning the igniter-grain tests are included in report LC(d)-433; general information is included in this report to summarize the motor qualification parameters.

During the RA-3 qualification, it was found necessary to remove the mylar diaphragm over the grain end to eliminate a large spurious torque transient for the first 300 msec of burning. Subsequent development tests showed the necessity for maintaining the relative humidity of the igniter below 70 percent. To do this, end closures were installed over the motor exhaust nozzles for shipment and handling and were removed before firing. Igniter and grain combinations were therefore qualified at 70 percent RH and the motor assembly (with nozzle closures) to 100 percent RH.

During the vacuum conditioning, the motors were held at 70°F. After removing from the conditioning chamber, the motor was installed in the test fixture, the firing chamber pumped to altitude, and the motor fired as quickly as possible. The motors were thus exposed to ambient temperature only about 1.5 hours, and the effect of temperature differences on motor performance should be minimal.

TABLE III

SUMMARY OF PRE-FIRING ENVIRONMENTAL CONDITIONING

Motor Number (S/N)	Configuration	Sterile Assem. Spec.	Non-Sterile	Pre-conditioning: Temperature & Humidity Type	Pre-conditioning: Temperature & Humidity (Hours)	Pre-conditioning: ET (Hours)	Pre-conditioning: Vibration Per TP	Pre-conditioning: Vacuum (Hours)	Firing Pressure
117	RA-3 with Mylar Diaphragm (Dwg. 8021000) Qualification Firings	LCS-120 except Formalin and Air Box not used for non-sterile assems. in next column	X	100% RH per TP B-2	0	None		0	SEA-LEVEL
127			X		0			0	
110					72		X	72	
133					48		X	48	
126					72		X	72	
114					72		X	264	
115					72		X	264	
132			X		0			0	
131					4		X	48	
134			X		0			0	
130			X		0			0	
120			X		0			0	
L-309	RA-4 W/O Mylar Diaphragm (Dwg. 802100E) Qualification Firings	LCS-120A		100% RH per TP B-29	0	None		0	FIRED IN VACUUM AT APPROXIMATELY 105,000 FEET
L-308					87		X	73	
L-310					86		X	73	
L-306					72		X	66	
L-305					72		X	66	
L-314					72		X	144	
L-316					89		X	70	
L-313					89		X	72	
L-304					0			21	
L-31?					72		X	101	
L-312					0		DPT	225	
L-317					72		X	142	
L-320					0			17	
L-303	RA-4 W/O Diaphragm (Dwg. 802134D and 802148) IGNITER QUALIFICATION FIRINGS	N.A.	N.A.	70% RH per TP B-27A W/Formalin	0	0		0	
L-42					0	0		68	
L-43					0	0		68	
L-39					72	12		69	
L-44					72	12		69	
L-41					72	12		108	
L-4?					72	12	X	66	
[illegible]					72	12	X	67	
L-4?					72	12	X	68	
17?	RA-3 Experimental W/O Mylar Diaphragm Otherwise per Dwg. 802100D	Assembled per LCS-120 or LCS-120A as applicable except Formalin and Filtered Air Box not used.		No pre-conditioning except 90 hours @ vacuum (12 microns) for L-30 and L-38					
?41									
119									
136									
135									
125									
L-302	RA-4 Experimental Dwg. 802100E								
L-37									
L-38									
L-36									
L-311									
L-30	LO-Pressure Grain and Nozzles								
L-31									
L-300									
L-47									

It should be noted that motor L-304 was used as a short-term age test specimen. This motor was assembled and stored until 6 April 1962 at the ambient conditions at the Aeronutronic facility. The purpose of this was to determine whether the free water in the propellant had an adverse effect on the hygroscopic $BKNO_3$ material in the igniter. No effects were noted; motor firing characteristics were completely normal.

4.2 COLD FLOW BALANCING OF EXHAUST NOZZLE THRUST

A major performance parameter for the spin motor is the requirement of primary torque vector alinement within 0.006 radian. This requires control of the effective thrust along each exhaust nozzle centerline within 0.50 percent. To meet this requirement, a procedure was developed to adjust the throat diameter of the individual exhaust nozzles after the complete manifold was assembled. This procedure is outlined in Test Plans B-4 and B-23 and is described more fully below.

The test fixture used in cold balancing is the same one used for firing qualification motors. This fixture is shown in Figure 1. It consists basically of a torque tube restrained in torsion and shear at the lower end by a thin (0.050-in. stainless-steel) diaphragm acting as a flexure pivot. At the upper end the tube is connected to two load cells by push rods located at 90 degrees to each other to measure pitch and yaw moments. The distance between the plane of the motor exhaust tubes and the diaphragm matches the nominal dimension to the capsule center of gravity and the transducer output calibrates directly into effective capsule pitch and yaw moments. Primary torque is measured by strain gages on the torque tube near the base. The axial component of thrust is not measured.

In early tests, it was found necessary to cover the fixture as shown in Figure 2, to eliminate erroneous data resulting from windage on the torque column and temperature effects on the transducers. The covers shield the fixture completely, with only about 1/4 inch of the exhaust nozzles protruding through. A plexiglass top was used to permit observation of the motor during test.

For cold balancing, the motor is assembled with a production-type case loaded with inert grain. It is mounted in the test fixture on three pads near the exhaust nozzles, duplicating the retromotor nozzle cutouts, and attached at the igniter end to the nitrogen tube, duplicating the attachment to the retro closure plug. The nitrogen

FIGURE 1. SPIN MOTOR STATIC TEST FIXTURE


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pressure is adjusted to result in a primary torque output of about 70 ft/lb. (Tests have shown that the cold flow unbalanced torque is not significantly affected by changes from 25 to 175 percent of this nominal value.) All cold flow balancing is done at an ambient pressure of about one psi (about 60,000 ft). Tests have shown that the cold flow balance results are effectively constant at altitudes above 60,000 ft.

In balancing the exhaust nozzles, the manifold assembly is operated with nitrogen and the pitch and yaw components of unbalanced torque measured. These are converted to an effective load (of known magnitude and direction) in the plane of the exhaust tubes. One or two nozzles (as required) are then enlarged to produce an effective load equal in magnitude and opposite in direction and thus reduce the unbalanced torque to zero. The effect of enlarging the nozzles is quite predictable, and an experienced technician can reduce the unbalanced torque to an acceptable value in three or four steps. All flight and qualification test motors have been balanced to a torque vector misalinement of 0.0025 radian or less, compared with a specification value of 0.006 radian.

During cold flow test, the nitrogen exhausts at about 2 lb/sec and is throttled from about 2200 psi to about 800 psi in the motor chamber. As a result, the nitrogen feed line and associated metal parts of the fixture are severely chilled during the test, causing fixture distortion and bias in the data. To isolate the true spurious torque, each motor was tested in each of the three angular positions, and from the resulting three apparent spurious torque vectors two were computed: a vector fixed in magnitude and direction (fixture error) and one of fixed magnitude but whose direction corresponds to the motor position (motor error). Determined in this manner, the measurements of motor error in the three positions are equal within $\pm$ 0.0003 radian on the average. For hot firings, these temperature considerations do not apply, and the fixture error is considered to be zero.

The actual adjustment of nozzle diameter has been done in two ways. For the RA-3 motors, the nozzles were contoured during final machining; adjustment during cold flow was done with a 3/8-in.-diameter abrasive stick with a tapered end. For the RA-4 motors, the nozzle throats were left as a straight bore during final machining. The throat contouring and all subsequent sizing was done with the special tool shown in Figure 3. This tool uses contoured stones on a split, expanding mandrel to obtain matched contours in the throats. As shown in Figure 4, it indexes on the inner surface of the exhaust cone to maintain throat alinement. The mandrel is rotated manually. Throat diameters are read with a split-ball, dial-reading hole gage; diameter measurements are repeatable within $\pm$ 0.0005 inch.

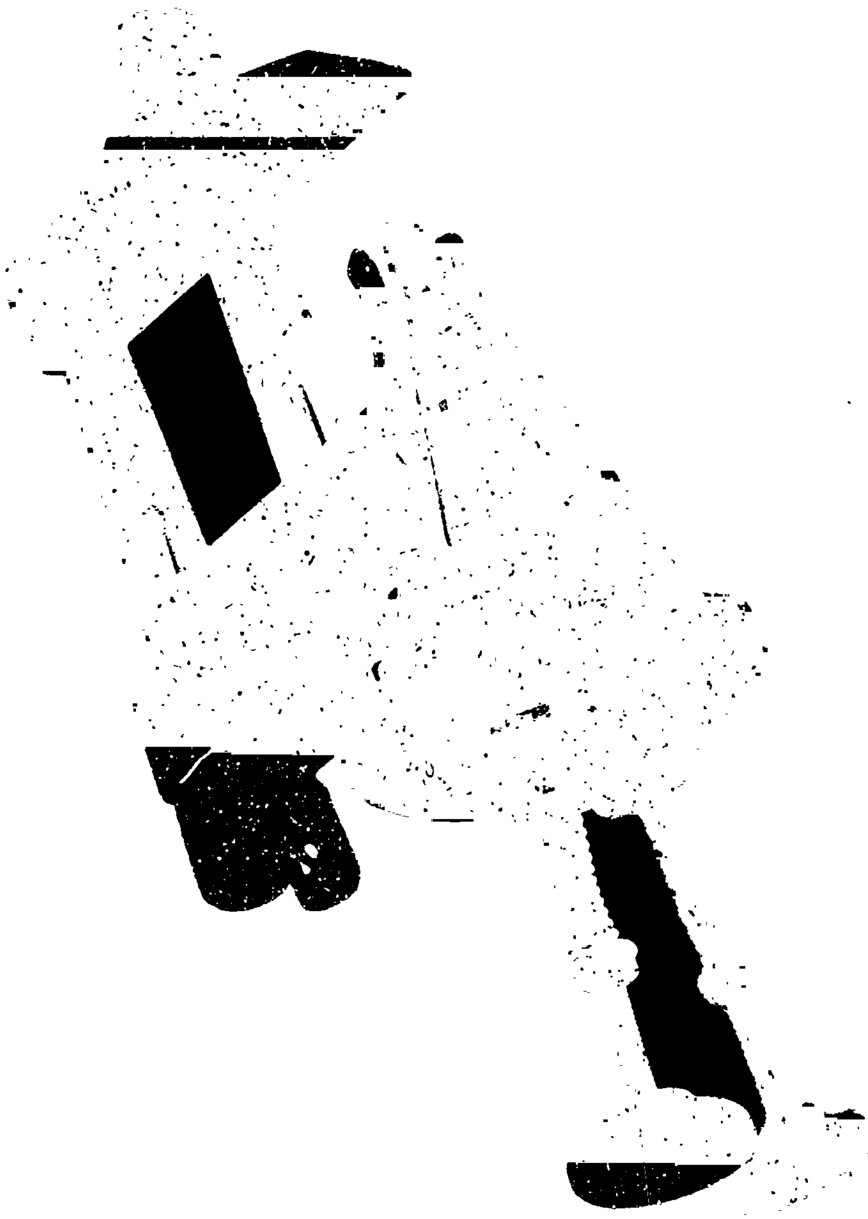

FIGURE 4. USE OF THE NOZZLE GRINDING TOOLS

In general, the cold flow balancing procedure provided predictable, consistent, and repeatable results. The change in the spurious torque due to nozzle diameter change for the RA-4 motors is shown in Figure 5. This curve shows that a change in nozzle diameter of 0.001 inch caused a corresponding change in tip-off moment of about 5 in/lb. In some cases, particular manifold assemblies exhibited erratic spurious torque characteristics, or required more than 0.005 inch change in nozzle diameter to balance. During the production of twenty RA-4 motors, two manifolds were rejected for these reasons.

Nozzle diameter and balance information is summarized in Table IV. Data are from motors which at the time of balancing were considered satisfactory for flight or qualification test.

TABLE IV

MANIFOLD BALANCE AND DIAMETER VARIATION

Motor Series	Sample Size	Primary Torque Vector Alinement (radians)			Difference in Diameter Betw[illegible] largest and smallest nozzle single manifold (inches)		
		Maximum	Minimum	Average	Maximum	Minimum	Average
RA-3	17	0.0045	0.0001	0.0021	0.0106	0.0008	0.00355
RA-4	18	0.0024	0.0004	0.00125	0.0038	0.0002	0.00205

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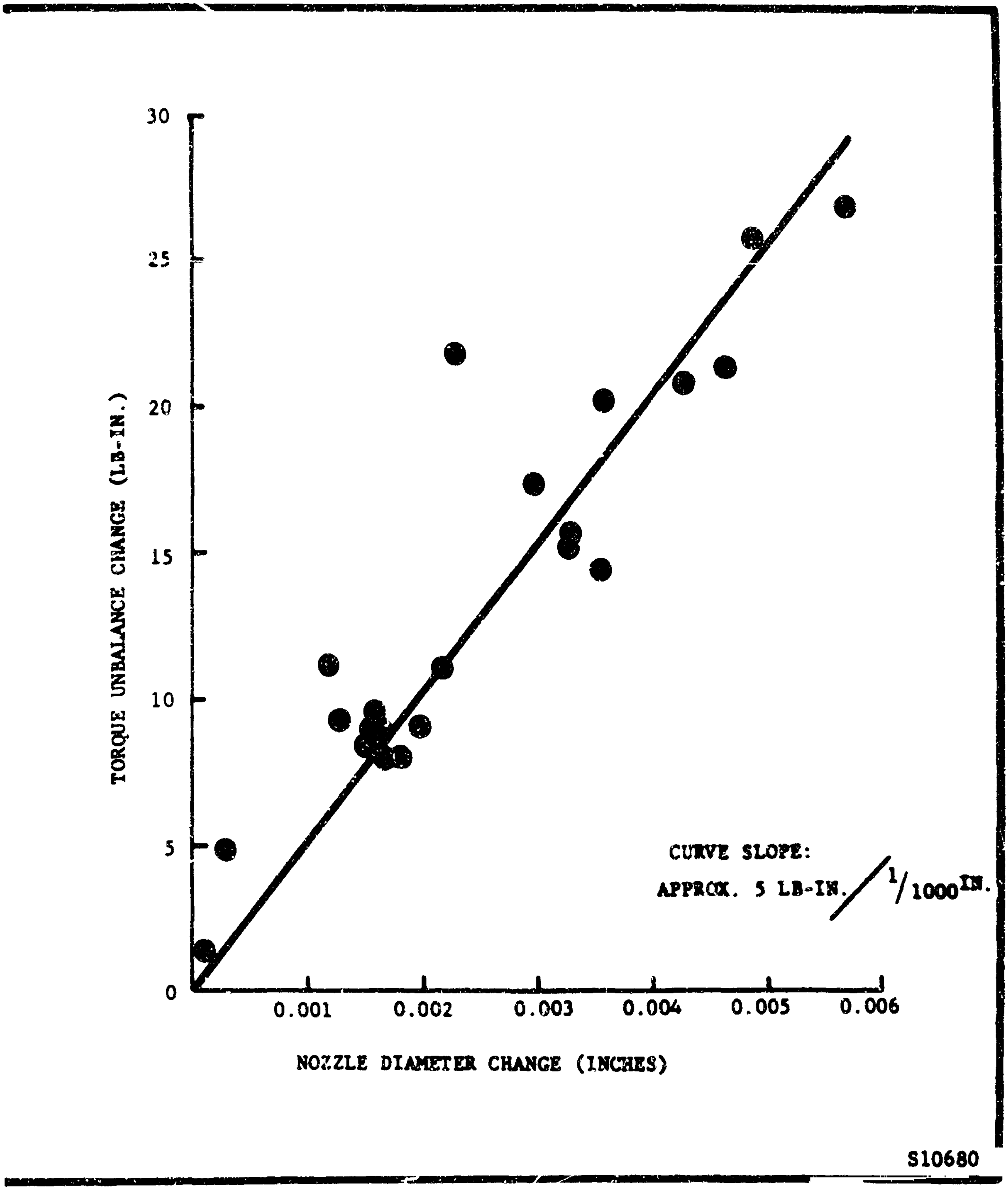


FIGURE 5. TORQUE UNBALANCE CHANGE VERSUS NOZZLE DIAMETER CHANGE (COLD FLOW BALANCING)

SECTION 5

MOTOR FIRING TESTS, RA-3 MOTORS

Data from the RA-3 firings are shown in Table V. All firings since the start of the qualification program are listed in chronological order. "Q" run numbers are those that were specified as qualification firings at the time; "E" runs are experimental, and the motors may incorporate minor changes from drawings and specifications.

Run numbers 104-Q through 149-Q are the RA-3 qualification firings. All but run 149-Q were made at sea-level ambient pressure. Run 149-Q and all subsequent firings were made in the vacuum chamber at Douglas, Long Beach, at a simulated altitude of about 105,000 feet (about 0.135 psi ambient pressure). The test fixture shown in Figure 2 was used in all RA-3 firings.

A major performance requirement for the spin motor is the tip-off angle that the capsule can tolerate. Due to system geometry required by other design considerations, very small differences in the three exhaust nozzle thrust vectors can cause significant pitch and yaw (tip-off) moments about the capsule center of gravity. The spin motor specifications visualize a steady tip-off torque (expressed as primary torque vector misalinement) that is proportional to the primary torque. Based on squared-off torque characteristics the effective thrust vector magnitude error is limited to about 0.15 lb, or to within about 0.35 percent, specified as 0.006 radian misalinement of the primary torque vector. Using this nominal and constant value, the resulting tip-off angle and cross axis velocity components were calculated for use in preliminary analyses of RA-3 dispersion.

SPIN MOTOR TESTS

QUALIFICATION AND EXPERIMENTAL

RA-3 SERIES

DRAWING NO 803:000

Test Run Number	106-Q	114-Q	118-Q	127-Q	130-Q	161-Q	162-Q	168-Q	169-Q
Date of Test	11-17	11-21	11-27	12-4	12-11	12-18	12-18	12-27	12-30
Case S/N	117	127	110	135	126	114	115	132	131
Manifold S/N	8	3	1	5	15	16	6	18	4
Burn Time (to 5%) (Sec)	-	1.25	1.33	1.340	-	1.440	1.370	1.315	-
Capsule Roll Rate (Rad/Sec)	-	27.15	25.36	26.41	-	29.10	28.33	26.24	-
Orthogonal Vector of Capsule Tip-off Angle (Rad)	-	0.0157	0.0136	0.0160	-	0.0212	0.0288	0.0226	-
Nozzle S/N 1	102	120	125	124	101	146	113	161	161
Nozzle S/N 2	117	135	136	129	128	147	143	168	164
Nozzle S/N 3	106	121	130	139	140	149	148	169	167
Nozzle Dia. 1	0.3636	0.3634	0.3628	0.3643	0.3662	0.3628	0.3659	0.3679	0.3635
After 2	0.3636	0.3632	0.3669	0.3659	0.3667	0.3663	0.3692	0.3539	0.3661
Balancing 3	0.3636	0.3640	0.3640	0.3664	0.3670	0.3651	0.3644	0.3633	0.3631
Grain Number	1141	1123	1137	1136	1121	1138	1140	1132	1133
Unid. Grind Number	43	42	43	42	41	43	43	42	42
Cast Date	11-10	10-26	11-2	11-1	10-26	11-3	11-3	10-31	10-31
Wt before Fire (Gm)	493	484	487	490	492	497	492	488	493
Wt after Fire (Gm)	155	178	156	176	175	151	156	(165)	-
Propellant Wt (Lb)	0.746	0.682	0.720	0.681	0.700	0.762	0.761	0.712	-
Actual Burn Time (Sec)	-	1.06	1.095	1.050	-	1.220	1.240	1.07	-
Torque (Lb-Ft-Sec)	-	67.61	70.57	64.14	-	72.73	70.61	65.59	-
Thrust (Lb-Sec)	-	126	131	123	-	135	132	122	-
I_{sp}	-	185	180	178	-	177	178	171	-
Conditioning (Hrs) T&H			TP	48	TP	TP	TP		4
VIB	None	None	TP	TP	TP	TP	TP	None	TP
(Hrs) VAC			TP	48	TP	264	264		48
Remarks	Base balanced in diameter not thrust 3400 installation load.	Igniter not cooked on runs 106, 114.	This & subs runs using gas igniter had baked ig.		Inertial spin fixture No torque or tip-off instrumentation			Nozzle truncated to ε = 2.25	Plastic cone fixt. no tip-off inst. primary torque inst. failed

Test Run Number	159-E	164-E	169-E	172-E	174-E	176-E	179-E	182-E	192-E	193-E	199-E
Date of Test	1-8-62	1-9	1-12	1-12	1-13	1-15	1-17	1-18	2-2	2-2	2-9
Case S/N	136	130	120	128	121	119	134	135	125	L-30	L-31
Manifold S/N	21	14	22	103-R	108-R	116-S	13	12	20	1M	108-RM
Burn Time (to 5%) (Sec)	1.28	1.34	1.29	1.29	1.36	1.37	1.77	1.33	1.36	1.25	1.13
Capsule Roll Rate (Rad/Sec)	28.80	25.05	26.76	25.08	25.23	30.39	32.26	24.45	29.18	31.54	31.66
Orthogonal Vector of Capsule Tip-off Angle (Rad)	-	0.0161	0.0632	0.0048	0.0127	0.0112	0.0079	0.0185	0.0049	0.0048	0.0032
Nozzle S/N 1	107	152	136	179	184	162	159	155	110	131	-
Nozzle S/N 2	116	154	145	180	185	163	172	157	116	166	111
Nozzle S/N 3	132	175	153	181	186	187	165	158	122	171	175
Nozzle Dia. 1	0.3630	0.3640	0.3676	0.3691	0.3636	0.3628	0.3650	0.3625	0.3669	0.3515	0.3506
After 2	0.3631	0.3626	0.3538	0.3645	0.3632	0.3638	0.3642	0.3659	0.3673	0.3497	0.3519
Balancing 3	0.3621	0.3641	0.3632	0.3686	0.3676	0.3634	0.3637	0.3645	0.3535	0.3555	0.3516
Grain Number	1118	1127	1112	1126	1113	1110	1135	1129	1120	1147	1149
Unid. Grind Number	41	42	41	42	41	40	42	42	41	45	45
Cast Date	10-24	10-30	1 -30	10-27	10-20	10-20	11-2	10-30	10-25	1-23	1-25
Wt before Fire (Gm)	489	486	489	490	494	494	486	489	492	485	489
Wt after Fire (Gm)	175	179	-	176	177	176	176	179	180	163	157
Propellant Wt (Lb)	0.692	0.678	-	0.692	0.698	0.705	0.691	0.682	0.688	0.712	0.732
Actual Burn Time (Sec)	1.06	1.11	1.07	1.06	1.11	1.16	0.990	1.06	1.11	1.01	0.980
Torque (Lb-Ft-Sec)	72.96	63.37	61.96	62.68	63.09	76.901	81.56	60.66	72.95	77.50	80.089
Thrust (Lb-Sec)	136	118	115	117	117	143	152	113	136	144	149
I_{sp}	196	174	-	169	168	203	220	166	198	202	203
Conditioning (Hrs) T&H											
VIB	None	None	None	None	None	None	None	None	None	None	None
(Hrs) VAC											
Remarks	No tip-off data gas leak into fixture			This and all subs w/o Mylar diaph., hub #3 rebuilt w/new carbon	Hub #8 rebuilt w/new carbon	Hub #16 rebuilt w/new carbon	RA-3 flight motor hang fire	RA-3 flight motor	All nozzle trim min of 0.003. Fixt. on I-Beam base. (All subs) RA-3 flight motor	Low pressure nozzles bottomed on fixt. due to heat expansion #1 Mod w/old carbon	Low pressure nozzles bottomed on fixt. due to heat exp. #108-R mod w/old carbon

Actually, in operating this close to null, the vector misalinement is random, varying in both magnitude and direction. To determine the effect of the measured tip-off torques, motor firing data were reduced on the digital computer, allowing accurate solution of the free body equations. It was found that relatively large tip-off torque peaks can be tolerated if the direction is relatively random, or if they occur later in the firing after the capsule has a degree of stability from the increasing angular velocity.

All motor firings were analyzed in this manner, and the final tip-off angle is used as a performance criterion, rather than specific values of torque vector misalinement. The results of the qualification firings have been used in final analyses of capsule dispersion.

In the early qualification firings, a large transient in torque vector misalinement occurred during the first portion of the firing. The tip-off torque data shown in Figure 6 show this transient clearly. These data are from Run 142-Q, and as [illegible]ed in Table V, resulted in a [illegible] orthogonal vector of 0.02[illegible] radian. It was theorized that this transient resulted from the exit nozzles not flowing full, and persisted until the upstream pressure reached the level corresponding to full flow conditions. The change in pressure during firing can be approximated by the primary torque curve shown on Figure 5.

To check this theory, the motor for Run 148-Q was modified by truncating the exit nozzles to an area ratio of 2.25 (compared to the flight motor ratio of 3.4) [illegible] that the nozzle would flow full at the ignition pressure. This [illegible]ted in the spurious torque data shown in Figure 7. Although the [illegible]nsient seems to remain, although highly attenuated, the tip-off torques shown result from thrust level variations of less than ± [illegible] (± 0.75%) and could result from random variations. Subsequent firings of standard nozzles in a vacuum did not confirm this, however, with tip-off torques similar to those in Figure 5

On Run 172-E and subsequent runs, the mylar diaphragm used to seal the downstream end of the grain was removed before firing. The starting transient again disappeared, indicating that the expulsion of the mylar caused the transient. Subsequent tests have confirmed this. Runs 172-E through 182-E show considerable improvement in tip-off angle, although it was still undesirably large.

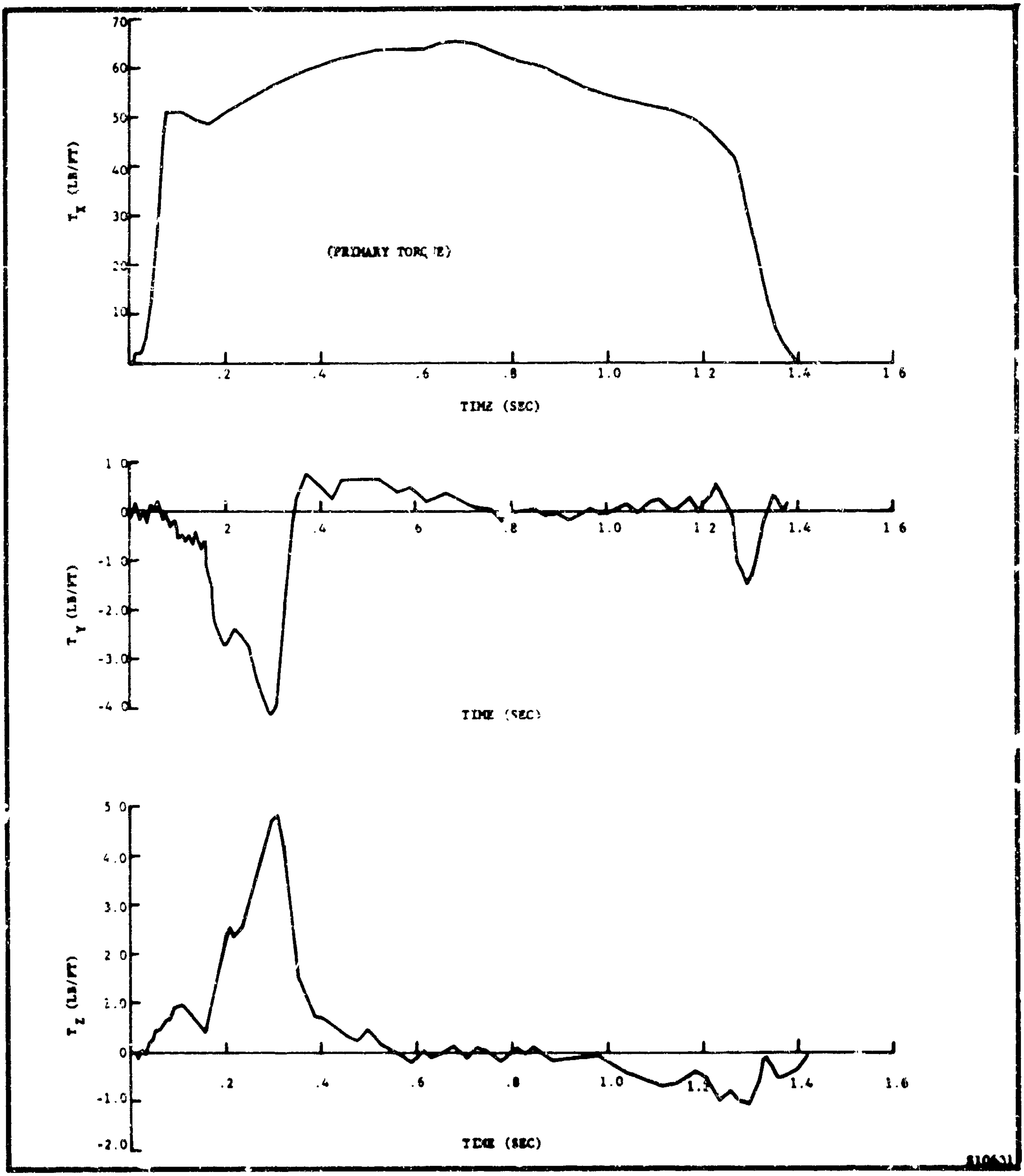


FIGURE 6. PRIMARY AND SPURIOUS TORQUES (RUN 142)

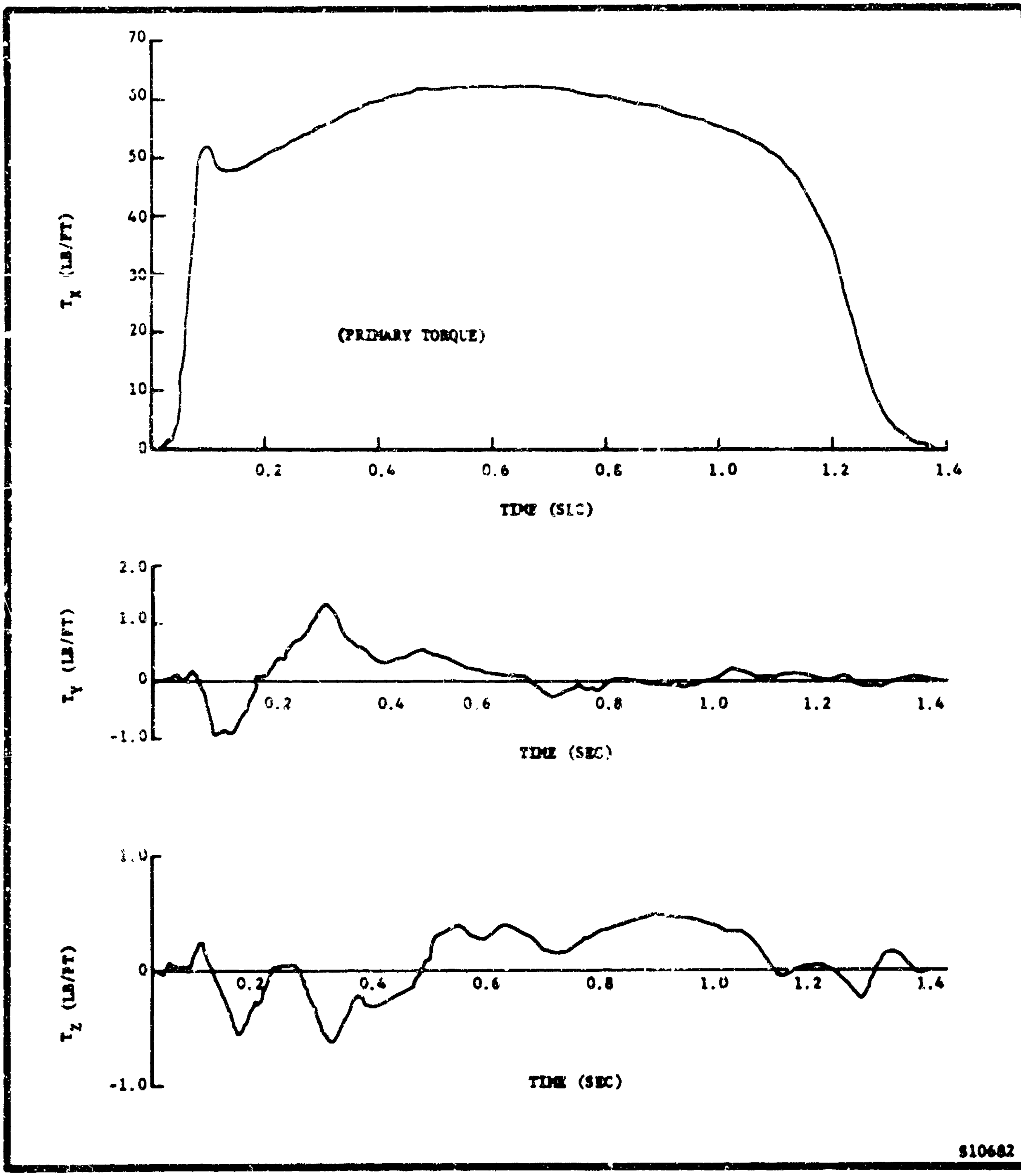


FIGURE 7. PRIMARY AND SPURIOUS TORQUES (RUN 148)

At that time, the exhaust nozzles were contoured during manufacture, and resized as required for cold flow balancing. As previously noted, only one or two of the three nozzles were enlarged in this process. The hot firing tip-off torques did not correlate with the cold flow results, apparently because of the minute differences in the nozzle contour that resulted from balancing. On Runs 192-E through 199-E, all nozzles were enlarged 0.003 inch with the same tool before balancing. Then they were balanced in the normal manner. The results are graphically apparent in Figure 8, which shows the data from Run 192-E. The ratio of specific heats, temperature, density, and flow rate of the cold flow nitrogen and hot exhaust gas are quite different; complete similarity of the nozzle contours is required to allow correlation of cold flow and hot firing characteristics.

Another possible cause of the tip-off torque variation is the flow disturbance downstream of the primary nozzle in the manifold, caused by shocking from sonic to subsonic flow. Two test motors were built with the primary nozzle removed. To retain the same motor output characteristics, it was necessary to reduce the chamber pressure from 800 psi to about 300 psi, that which prevails upstream of the exhaust nozzles in the standard motor. The mixture ratio and oxidizer grind ratio of the stock grain were altered to provide the burning rate required at the reduced pressure, resulting in an increase in burning temperature from about 3700 to 4200°F. These motors were fired in Runs 193-E and 199-E; tip-off angles were less than 0.007 radian. Subsequent tests indicated, however, that no significant improvement in tip-off torques could be obtained by elimination of the orifice alone, as discussed later in the RA-4 firings. Rather than arbitrarily make such a major change in the basic motor design, the primary orifice was retained.

The performance of the RA-3 spin motor, as predicted for flight motors, is summarized in Table I of this report. To make this prediction as reliable as possible, care was used to base each parameter on motor tests that were truly representative of the corresponding characteristics in flight motors. Also, experimental as well as qualification test data were used where the data were representative. The test runs used in computing each of the parameters are listed in Table VI, in addition to the specific reasons for not using those runs considered non-representative of flight motor performance.

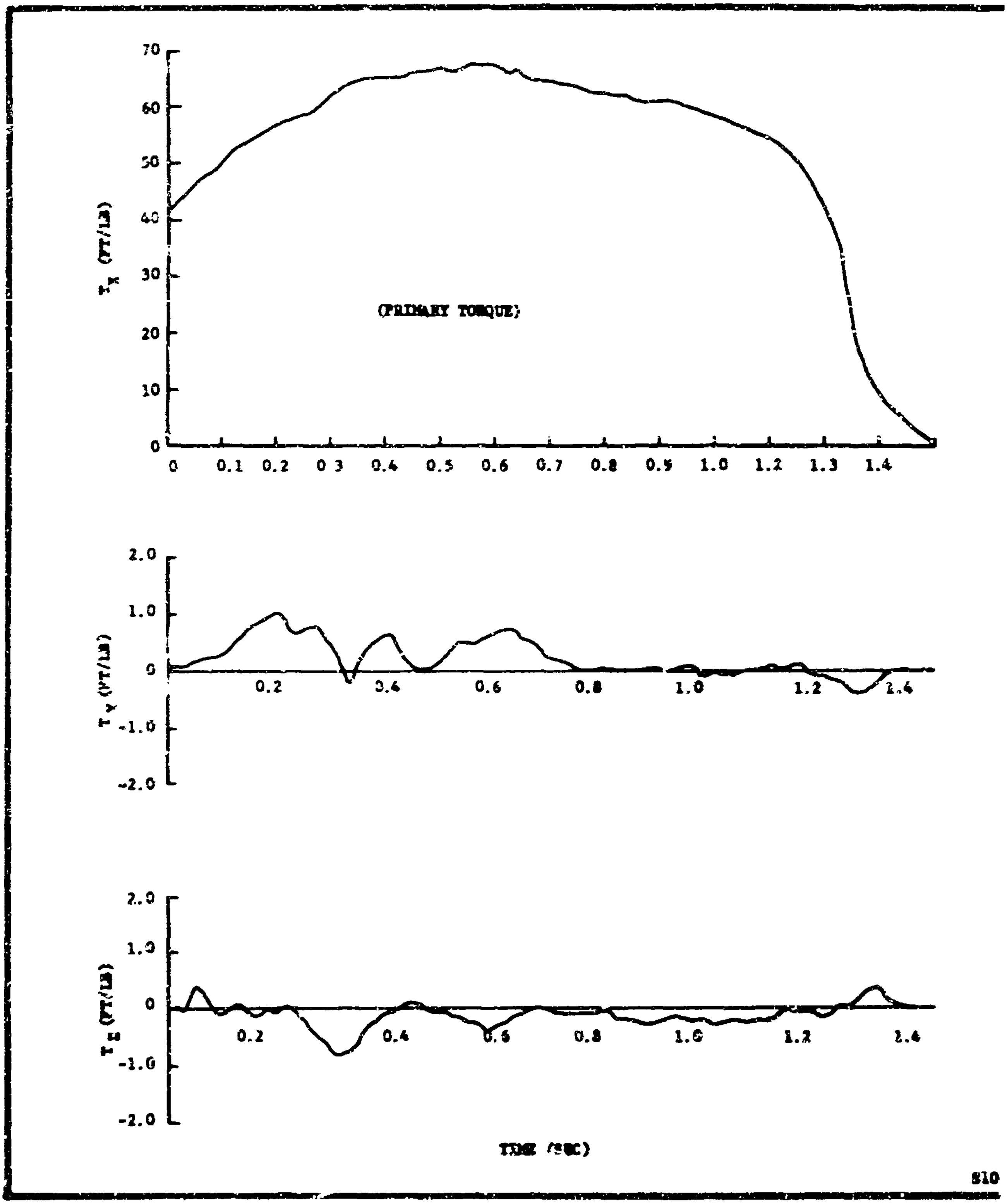


FIGURE 8. PRIMARY AND SPURIOUS TORQUES (RUN 192)

TABLE VI

PERFORMANCE DATA SELECTION FOR RA-3 FLIGHT MOTORS

Parameter	Runs Used	Runs Not Used and Reason
Tip-off Angle	172	104 thru 169 - These motors had mylar
	174	diaphragm
	176	
	182	179 - Marginal ignition performance
	192	193, 199 - Non-standard configuration;
		Low pressure grain
Specific impulse, burn time, roll rate	114	104 - data not available
	118	130 - data not available - firing on
	127	special spin-up fixture
	141	148 - Non-standard configuration - exit
	142	nozzles truncated to simulate vacuum firing
	159	149 - data not available
	164	179 - Marginal igniter performance
	169	193, 199 - Non-standard configuration;
	172	Low pressure grain
	174	
	176	
	182	
	192	(Note: ISP not available from run 169)

26

SECTION 6

MOTOR FIRING TESTS, RA-4 MOTORS

From the results of the RA-3 firings, it was apparent that with relatively minor design changes, the spurious torque performance of the spin motor could be significantly improved. The changes that were incorporated are as follows:

(1) The mylar seal and epoxy spacer at the downstream end of the grain were removed.

(2) The exhaust nozzles were contoured and sized with a special grinding tool.

(3) The GAI-3A igniter was replaced with a tailored igniter using all $BKNO_3$ as the ignition charge.

(4) The configuration of the igniter installation seal was modified to increase the seal reliability.

(5) The oxidizer coarse/fine grind ratio was changed from 46/23 to 40/29 to slightly increase the burning rate.

In addition to the spin motor product improvement program, a concurrent test program was conducted to determine the effects of the spin motor exhaust gases on the capsule tip-off torque. These tests involved the use of a test fixture that simulates the separation systems, so the spurious torque performance of the spin motor cannot be isolated. Four of the RA-4 qualification tests were conducted on this fixture. The spurious torque data from these firings are included separately; other parameters of motor performance are included with the results of those conducted on the torque fixture.

Data from the RA-4 firings are shown in Table VII. All firings since the start of the Engineering Product Improvement program are listed in chronological order. "Q" run numbers are those that were specified as qualification firings at the time; "E" runs are experimental, and the motors may incorporate minor changes from drawings and specifications.

Motors used in test numbers 214 through 219 were intended to confirm suitability of the design changes and to determine the effect of eliminating the primary orifice. Runs 215 and 219 used the low pressure (no primary orifice) motors. From the results of these tests, it was concluded that the improvement in spurious torque characteristics was due primarily to the changes in exhaust nozzle contour and deletion of the mylar diaphragm. Rather than consider such a major change in motor design, the low pressure system was dropped.

During fabrication of the RA-4 motors, two different nozzle trimming tools were used. From the early test results it appeared that the spurious torque performance of motors built with tool No. 2 was inferior to those using No. 1 Consequently, only four motors were built using tool No. 2. These were fired in test numbers 230, 248, 249, and 262. All flight motors were built using nozzle tool No. 1.

Tests number 264 and 266 show excessively large tip-off angles. During balancing of these manifolds, it was noted that the internal cylindrical section that results from rough machining was shorter than normal on one of the nozzles. This dimension is not controlled directly, but rather is determined by the intersection of the throat diameter with the entrance and exit cones. Although the assemblies appeared to balance in the normal manner, the variation in appearance and "feel" was recorded on the balance data sheets. Even so, the motors were specifically not assigned for flight, but were considered satisfactory for qualification test. From the firing test results, this was obviously an error. Figure 9 shows the primary and spurious torque curves for Run 252. These results are typical of the RA-4 motor performance. The results of Run 266 are shown in Figure 10. The pitch and yaw torques are relatively constant and are of large magnitude, indicating steady performance but no correlation with cold flow balance. Because of the known variation in nozzle contour in these motors, the resulting tip-off data are not used in predicting flight motor performance.

TABLE VII

SPIN MOTOR TESTS

QUALIFICATION AND EXPERIMENTAL

RA-4 SERIES

DRAWING NO. 002100K

Test Run Number	214-E	215-E	218-E	219-E	230-Q	248-Q	249-Q	252-Q	253-Q	254-Q	260-Q	261-Q	262-Q	264-Q	265-Q	266-Q	270-E	271-E	272-Q
Date of Test	2-22-62	2-22	2-26	2-26	3-7	3-16	3-16	3-23	3-23	3-26	3-30	3-30	4-7	4-10	4-11	4-12	4-16	4-16	4-16
Case S/N	L-302	L-300	L-37	L-47	L-309	L-308	L-310	L-306	L-305	L-314	L-316	L-313	L-304	L-319	L-312	L-317	L-58	L-50	L-320
Manifold S/N	L-108	L-102	L-103	L-106	L-122	L-101	L-109	L-116	L-119	L-113	L-111	L-115	L-121	L-112	L-105	L-117	L-100	L-107	L-118
Burn Time (to 5%) (Sec)	1.12	1.09	1.15	1.10	1.18	1.18	1.14	1.10	1.13	1.19	1.15	1.12	1.07	1.15	1.11	1.12	1.14	1.10	1.12
Capsule Roll Rate (Rad/Sec)	28.30	28.78	31.95	31.57	32.62	32.40	32.59	32.01	32.45	32.70	32.57	31.89	30.84	33.75	32.70	33.58	33.27	33.37	32.97
Orthogonal Vector of Capsule Tip-off Angle (Rad)	0.0026	0.0096/ 0.0136	0.0083	0.0067	0.0088	-	0.0099	0.0037	0.0064	0.0109/ 0.0067		0.0073	0.0032	0.0268	0.0036/ 0.0087	0.0328	0.0066	0.0083	0.0080
Nozzle S/N 1	201	211	205	212	207	200	228	233	236	245	238	247	202	216	237	248	234	214	268
Nozzle S/N 2	210	220	223	213	208	206	224	253	255	246	232	249	203	229	254	256	230	231	269
Nozzle S/N 3	217	223	226	225	209	215	227	263	264	262	243	261	206	235	259	258	267	239	270
Nozzle Dia. 1	0.3453	0.3444	0.3426	0.3419	0.3470	0.3424	0.3422	0.3427	0.3421	0.3455	0.3440	0.3434	0.3436	0.3478	0.3456	0.3420	0.3479	0.3421	0.3433
After 2	0.3448	0.3430	0.3452	0.3421	0.3447	0.3436	0.3449	0.3440	0.3421	0.3450	0.3439	0.3427	0.3433	0.3457	0.3457	0.3422	0.3422	0.3460	0.3425
Balancing 3	0.3456	0.3430	0.3433	0.3419	0.3432	0.3458	0.3439	0.3439	0.3436	0.3421	0.3453	0.3443	0.3437	0.3421	0.3439	0.3422	0.3449	0.3479	0.3448
Grain Number	1152	1151	1157	1170	1165	1163	1164	1156	1154	1167	1169	1165	1154	1176	1165	1171	1180	1177	1183
Oxid Grind Number	46	45	46	47	47	47	47	[illegible]	46	48	48	48	46	49	48	48	50	49	50
Cast Date	2-14	2-13	2-19	2-23	2-23	2-23	[illegible]	2-17	2-16	3-7	3-8	2-26	2-16	3-9	2-26	3-8	3-21	3-13	3-20
Wt before Fire (GM)	487	491	489	492	493	489	490	493	490	491	490	488	484	491	488	488	493	492	498
Wt after Fire (GM)	184	185	150	162	157	156	56	161	159	153	157	156	185	157	155	154	157	156	167
Propellant Wt (Lb)	0.669	0.675	0.749	0.727	0.740	0.734	0.737	0.732	0.744	0.761	0.736	0.734	0.660	0.736	0.734	0.736	0.741	0.740	0.730
Actual-Burn Time (Sec)	0.760	0.895	1.085	0.970	1.06	1.015	1.025	0.975	1.005	1.000	1.000	0.998	0.880	0.923	0.96	0.973	1.001	0.978	0.977
Torque (Lb-Ft-Sec)	71.57	72.76	80.80	79.82	80.00	81.90	82.43	81.00	82.99	82.71	82.38	80.67	73.75	82.90	82.79	83.52	82.8	83.55	82.06
Thrust (Lb-Sec)	133	135	150	148	149	152	153	151	153	154	153	150	137	154	156	155	154	155	153
I_{sp}	199	200	200	203	202	208	208	206	206	207	208	204	208	209	209	210	208	210	210
Conditioning (Hrs) TMP						67	86	72	72	78	89	89	None	72	None	72	None	None	None
VIB	None	None	None	None	None	TP	TP	TP	TP	TP	TP	TP	None	TP	NPT	TP	None	None	None
(Hrs) VAC						73	73	66	66	144	70	72	21	108	225	142	90	95	17
	Nozzle Tool #1 Oxid. Grind 40-29 "C" Basket Ignit r MOD, 12-2D 34-2E	Nozzle Tool #1 Lo Pressure "C" Basket Ignit r MOD, 12-2D 24-2E	Nozzle Tool #1 Oxid. Grind 40-29 "C" Basket 8-2D -03. "C" Ring 33-2E clamped in throat	Nozzle Tool #1 lo pressure "C" basket 8-2D 33-2E	1st Qual. Firing. Nozzle Tool #2. This & all subs oxid. grind 4-29	Nozzle Tool #2 One Dynamic Fixture Nut Failure destroyed Tip-off data.	Nozzle Tool #2	Nozzle Tool #1 TQ Fixt.	Nozzle Tool #1 TQ Fixt.	Nozzle Tool #1 G.O. Fixt. W/O Hot Heat Shield Cocked	Nozzle Tool #1 TQ Fixt.	Nozzle Tool #1 TQ Fixt.	Nozzle Tool #2 G.O. Fixt. Hat w/outer cover & inner ring. Pumped 12 hrs. Black Heat Shield Age Test Motor.	Nozzle Tool #1 Nozzle #2 had sharp throat.	Nozzle Tool #1 G.O. Fixt. TP strain had teflon removed and firing on set up from #262	Nozzle Tool #1	S/N 100 would not balance in acceptable diameter range	Epoxy ridge in lug #231 - Reject. balanced before firing Nozzle Tool #1	Nozzle Tool #1

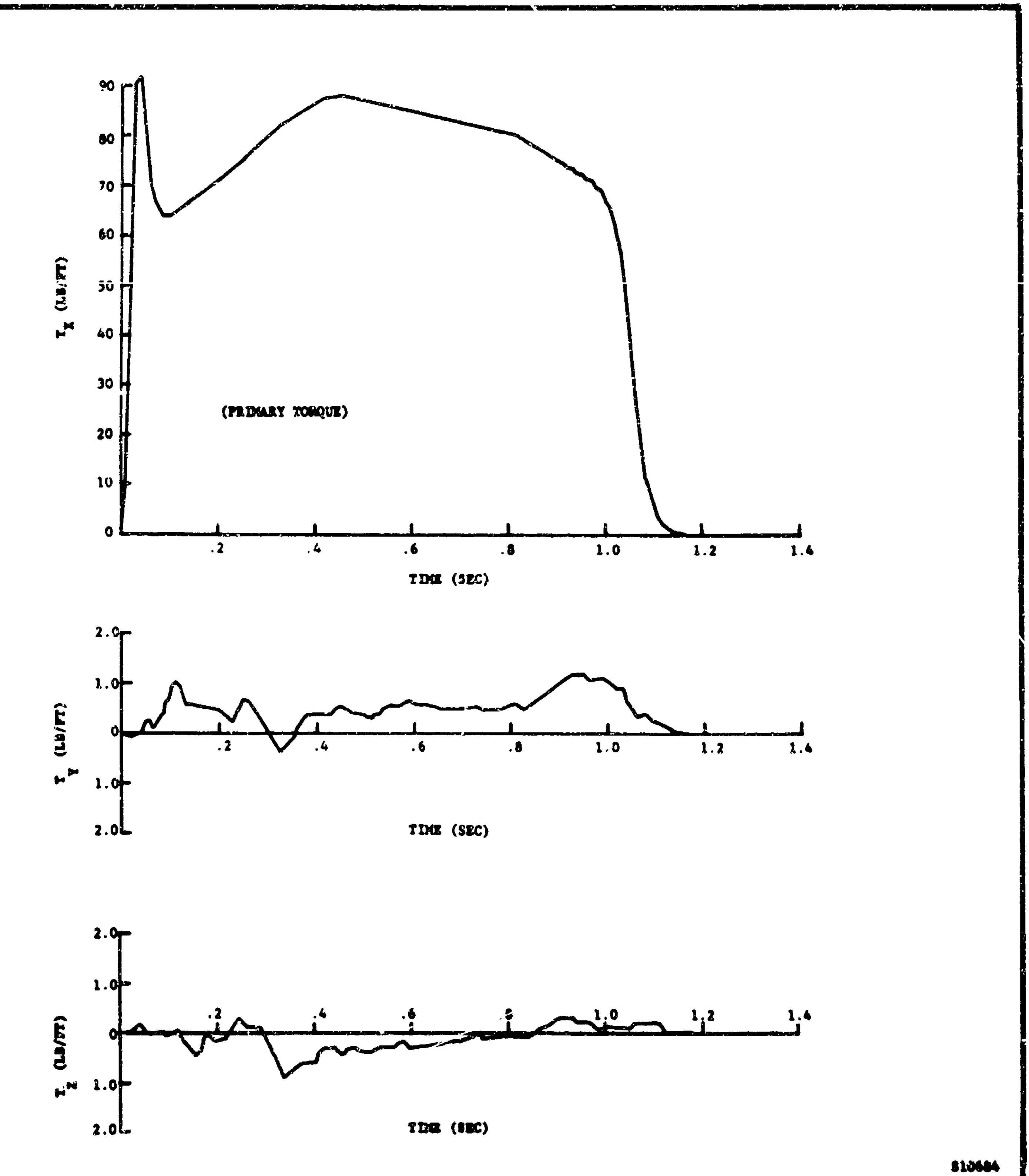


FIGURE 9. PRIMARY AND SPURIOUS TORQUES (RUN 252)

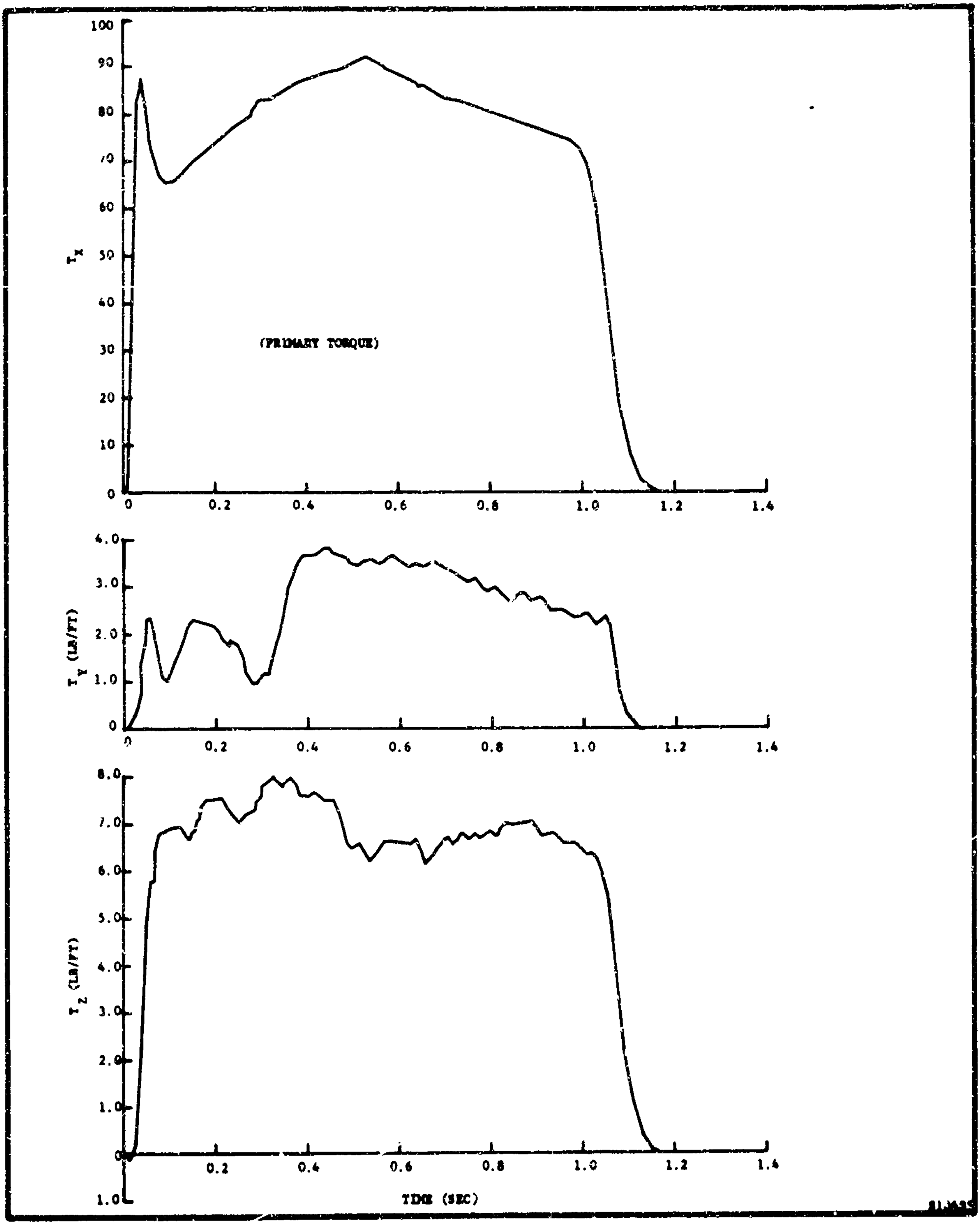


FIGURE 10. PRIMARY AND SPURIOUS TORQUES (RUN 266)

The performance of the RA-4 spin motor, as predicted for flight motors, is summarized in Table II of this report. To make this prediction as reliable as possible, care was used to base each parameter on motor tests that were truly representative of the corresponding characteristics in flight motors. Also, experimental as well as qualification test data were used where the data are representative. The test runs used in computing each of the parameters are listed in Table VIII, along with the specific reasons for not using those runs considered non-representative of flight motor performance.

TABLE VIII

PERFORMANCE DATA SELECTION FOR RA-4 FLIGHT MOTORS

Parameter	Runs Used	Runs Not Used and Reason
Spin motor tip-off angle	214E, 252Q, 253Q, 260Q, 261Q, 272Q,	215E, 219E, -Low pressure grain, 218E - O'ring clamped in throat 230Q, 249Q, - Nozzle tool No. 2 248Q, 254Q, 262Q, 265Q, - Fired on gas dynamic fixture. 264Q, 266Q, 270E, 271E, 274E - Non-standard configuration in exit nozzles.
Gas dynamic tip-off angle	254Q, 262Q 265Q	All other runs not made on this test fixture, except 248Q - data lost due to failure of symmetrical vent.
Specific impulse burn time capsule roll rate	248Q, 249Q 252Q, 253Q 254Q, 260Q, 261Q, 264Q, 265Q, 266Q, 270Q, 271Q,	215E, 219E - Low pressure grain All others - temperatures conditioning was done during vacuum. Variations from short, or no temperature (vacuum), conditioning may invalidate data.

SECTION 7

TESTING OF SPIN-UP SYSTEM

7.1 TEST SET-UP

In addition to the tests of the spin motor as a component, tests were conducted on the entire spin-up system. The test fixture simulated the bus-capsule system to the degree necessary to provide representative dynamic loads on the capsule from the spin motor exhaust gases.

All tests were conducted in the Douglas Aircraft Company, Long Beach, vacuum chamber. The test fixture is described on Drawing 805816; flight hardware used in the various tests included the motor support structure (Drawing 800003), the symmetrical vent (Drawing 800112), the radiation shield (Drawing 800120), and the spin restraint (Drawing 800131). The test fixture set-up in the vacuum chamber is shown in Figure 11.

All tests were conducted at a pressure of about 7 mm Hg, equivalent to an altitude of slightly over 100,000 feet.

The test fixture was designed to allow capsule-bus orientation through 360 degrees of rotation on the Z-axis and through 21 inches of separation along the Z-axis. The separation acceleration and velocity due to both spin motor axial thrust and exhaust gas pressures were simulated; the angular acceleration of spin-up was not simulated. Angular orientation and separation position were obtained by rotating or traversing the bus simulator; rotation velocity was about 0.5 radians/sec. Both the capsule and bus simulators are essentially rigid in rotation about the X and Y axes. With respect to transverse loads at the plane of the spin motor exhaust nozzles, the spring rate of the capsule simulator is about

FIGURE 11. TEST FIXTURE SET-UP IN VACUUM CHAMBER

45,000 lb/in. The spring rate of the bus simulator for loads in the three axes is from 1700 lb/in. to 3500 lb/in. depending on load direction. The flexibility of the bus relative to the capsule presents difficulties in analyzing the spin restraint test results.

7.2 SPIN RESTRAINT

During the development and test firings of the RA-3 spin motors, considerable difficulty was experienced in reliably obtaining spurious torques at the low level required. At that time, the desirability of incorporating a restraint device for the spin-up period was recognized and implemented. Subsequently the spin motor performance indicated that the restraint was not essential, but it was retained as further assurance of minimum tip-off from spin motor spurious torque.

The spin restraint used on RA-4 and RA-5 utilizes the large inertia of the bus to furnish restraining shear loads at the plane of the spin motor exit nozzles. The restraint acts for slightly less than one inch of capsule separation. Restraining loads are applied to the central hub of the spin motor and are transferred through spring loaded arms to the bus structure. The flight spin restraint is shown in Figure 12 on the vibration test fixture.

In limiting the capsule tip-off, the significant restraining period is that before spin-up is started and during the first portion of the spin-up when the angular velocity is low. As the rotational speed increases, the (gyroscopic) inertial stiffness increases as the square, so the need for restraint rapidly diminishes.

To determine the optimum restraint length, a computer program was set-up representing the dynamic system, and a series of runs were made to determine final tip-off angle versus restraint length. The model assumed restraint in the lateral direction at the spin motor hub, but assumed no angular restraint. Spin-up torque applied was from a typical actual spin motor firing. Tip-off torque was assumed to be a constant 2 ft-lb

The tip-off torque was applied two ways: (1) body fixed - that is, as if the misaligned primary torque vector rotates with the capsule, or as if the equivalent tip-off load in the plane of the spin motor nozzles rotates with the capsule, and (2) space fixed - that is, as if the misaligned torque vector stays fixed in relation to the bus as the capsule rotates. The body fixed case corresponds to all tip-off load being generated as a constant thrust misalignment in the spin motor; the

FIGURE 12. FLIGHT SPIN RESTRAINT ON VIBRATION TEST FIXTURE

space fixed case corresponds to all tip-off loads being generated as a bus function - for example, by unbalanced pressure on the retro nozzle, possibly resulting from unsymmetrical venting of spin motor exhaust gases.

The results of these calculations are shown in Figure 13. It is noted that for a body-fixed spurious torque, the optimum length of restraint is about 2 inches, and that about 75% of the benefit obtainable is provided by a 1-inch restraint. The 1-inch length is very convenient, since it allows fixed restraining fingers to be inserted between the spin motor exit tubes. The fixed relationship between angular and linear acceleration of the capsule insures separation of more than one inch before rotating to a position of interference.

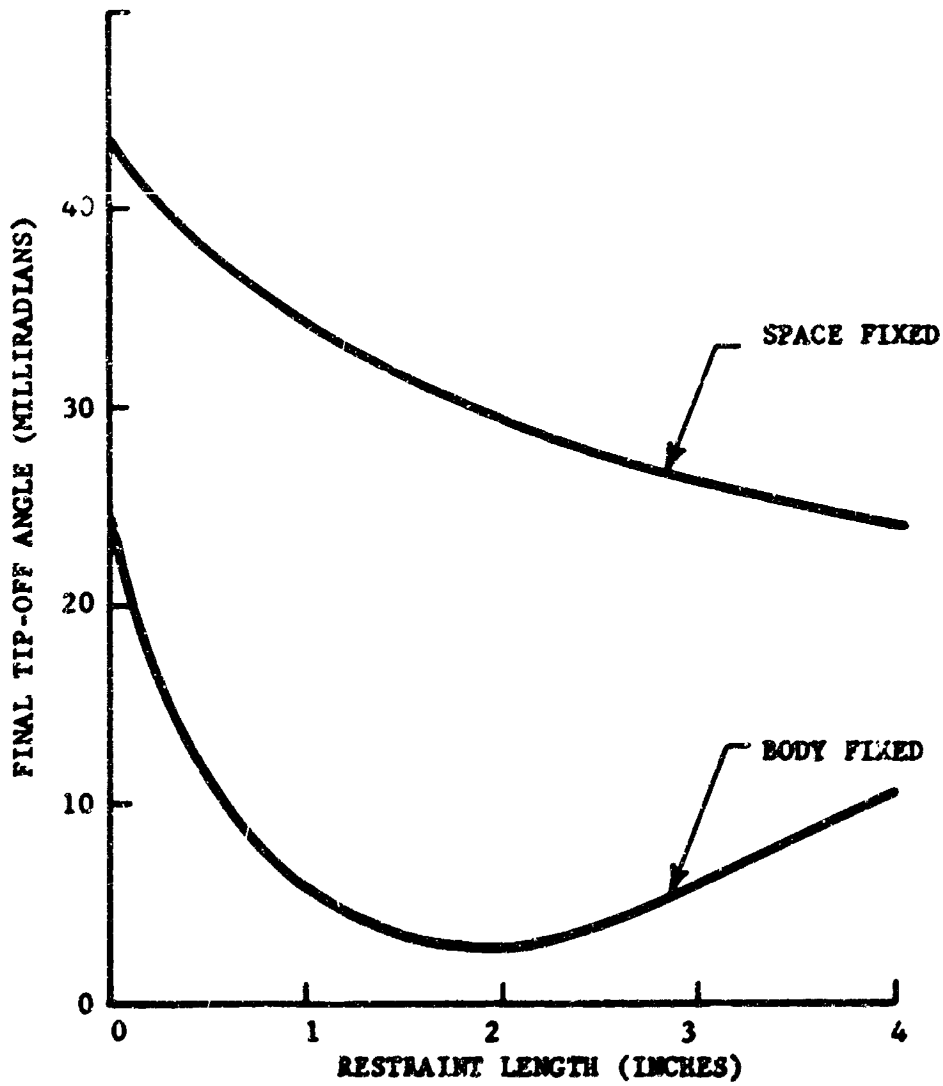
In its final configuration, the restraint consists of a center hub contacting the spin motor at three points. Teflon shoes are used at the contact points. The restraint is supported on three legs which are spring mounted to the bus structure. The spring rate is about 340 lb/in. for any deflection in the plane of the restraint. This allows motion during the boost phase vibration when the restraint loads are high, but restrains the capsule during spin motor firing, when the lateral loads are small - less than 1 pound for the results shown in Figure 13, and less than 1/2 pound predicted from motor test data.

The spin restraint was tested in vibration as part of the complete capsule system. The effect of the restraint loads on the vibration modes of the capsule was negligible. No undesirable effects on the spin motor installation were observed.

The restraint was installed in the separation test system for firing tests. The installation in the bus simulator is shown in Figure 14. Linear potentiometers were attached to the hub to monitor restraint position relative to the bus.

In mating tests with the capsule simulator, it was determined that the best installation that can reasonably be made results in a lateral off-set of about 0.003 in. From previous firings it appears that this lateral displacement of the spin motor hub at approximately 1-inch separation is equivalent to 0.005 radians or less final tip-off angle. This comparison is quite conservative, since the comparative tip-off angular velocities would not apply with the restraint in place.

It was found during cold flow test that the gas pressures on the bus cause it to deflect, resulting in a transverse (upward) displacement at the spin restraint. The displacement is in the order of 0.025 inch



S11288

FIGURE 13. FINAL TIP-OFF ANGLE OF CAPSULE AS RESULT OF CONSTANT 2 FT-LB SPURIOUS TORQUE DURING SPIN-UP

FIGURE 14. RESTRAINT INSTALLATION IN THE BUS SIMULATOR

At a spring rate of 340 pounds, this is equivalent to a load of 8.5 pounds or a tip-off moment of about 250 in.-lb. This must be subtracted out of test firing data for tip-off analysis; it does not apply to the actual separation, of course.

In general, the spin restraint performed satisfactorily, showing no tendencies toward resonant vibration, excessive deflection, or binding. Specific firing test results are included in following sections of this report.

7.3 COLD FLOW TESTS ON THE GAS DYNAMIC FIXTURE

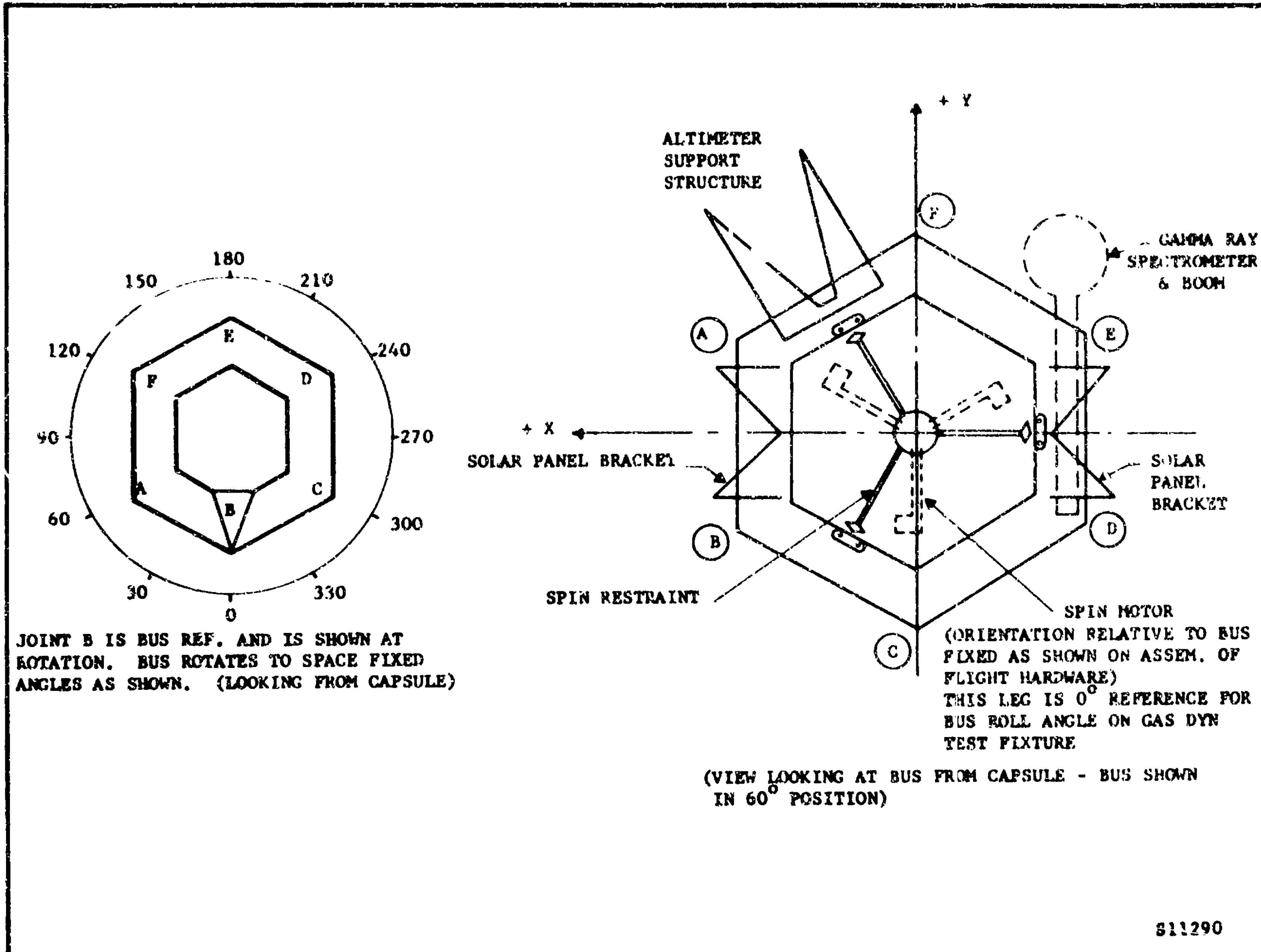
Cold flow tests were conducted on the gas dynamic fixture to (1) gain an insight into the nature of the gas dynamic induced (spurious) torque, (2) establish a criteria for the design of a spin restraint, and (3) determine the least favorable capsule-bus orientation for the live motor firings.

It was required to determine the functional relationship of spurious torque phase and magnitude, to separation distance, rotation, and subsequently time.

The set-up was made in the DAC vacuum chamber using a spin motor assembly which had first been balanced by a three position cold flow in the "static test fixture".

Transducers were mounted on the gas dynamic fixture for the measurement of (a) spurious torque about two orthogonal axes and (b) pressures on the retromotor dome and nozzle. The calibrations were made using manometer and dead-weight references.

Initial cold flow tests were conducted at a fixed rotation and separation, with the symmetrical vent in position. The altitude was approximately 60,000 feet. Rotation was in 15-degree increments over a 120-degree sector while separation was in 2-inch increments over a distance of 21 inches. Separation distance is zero with the bus and capsule mated, and increases in positive magnitude as the capsule separates. The angular position zero reference is shown in Figure 15. The magnitude and sign of the two orthogonal components of spurious torque were recorded at each position of separation and rotation (Runs 381 to 479, February 5, 1962). The magnitude and phase of the vector were then plotted on polar coordinates, for a 0- to 21-inch separation distance, with rotation (0 to 120 degrees) as a parameter. It had been hoped that the phase of the



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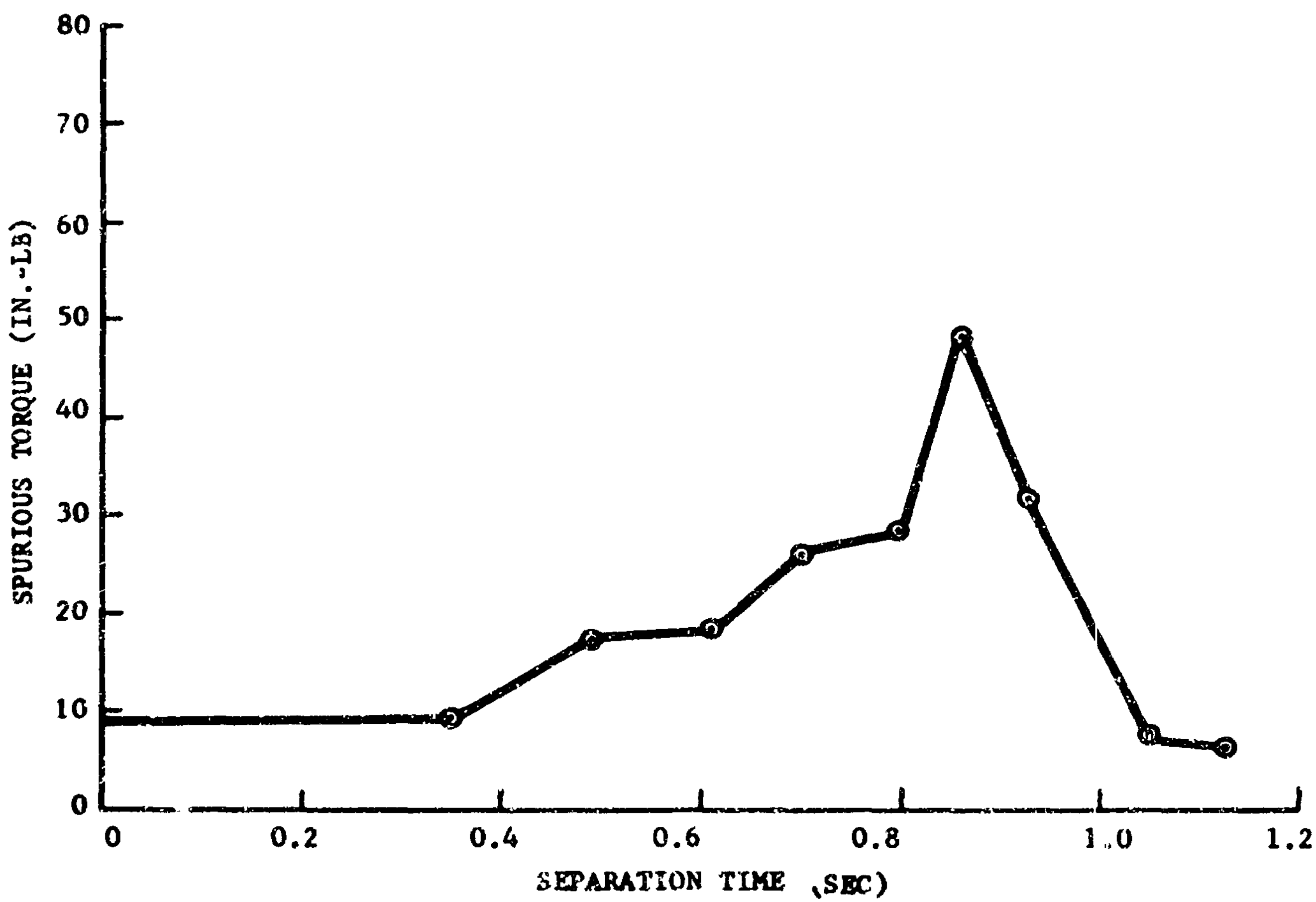
spurious torque would indicate some pattern of consistency for various relative regular positions, i.e., either remaining constant indicating a body (capsule) fixed phenomena or rotating in a manner analagous to bus rotation indicating a space (bus) fixed phenomena. However, no pattern of consistency became apparent; the phase appeared to be uniformly random. A consistent pattern was revealed, however, in the absolute magnitude versus separation distance (time) as shown in Figure 16. As can be seen there was an initial torque unbalance of 10 in.-lb which built rapidly to a value of 50 in.-lb and then rapidly diminished to near its original value.

It was discovered at this time that the symmetrical venting device had been weakened by the repeated cold flow tests. Thus a sheet metal aluminum liner was added to its interior to provide stiffening. As later became apparent, during the hot motor firings, it was this step which severely altered the nature of the measured spurious torque. Eliminated was the large spike at 12 inches (0.86 sec) of separation. This spike was apparently due to an impulse imparted to the retromotor nozzle by a buckling of the symmetrical venting device.

Subsequent to the gathering of the foregoing data, a question arose as to whether sonic flow was being incurred at the exit of the symmetrical venting device. Thus dynamic separation tests were conducted in which the nature of the spurious torque was observed for various altitudes. It was observed that there was a considerable variation in the magnitude of the spurious torque for altitudes less than 90,000 feet; it became oscillatory at altitudes less than 40,000 feet. Since the earlier tests had been run at altitudes of only 60,000 feet, their validity was questioned. The flow may not have been sonic at the exit of the symmetrical venting device. Subsequent cold flow tests were conducted at altitudes of 110,000 feet which represented near ultimate chamber capabilities.

Additional dynamic separation cold flow tests were conducted over a 120-degree separation angle sector in 15-degree increments. Data were gathered (a) with the symmetrical vent and radiation shield in position and (b) without the symmetrical vent, but with a simulated thermal radiation shield in position. It was necessary to use a simulated radiation shield, since the multilayer mylar shield is severely damaged and unusable after a few cold flow tests. The shield consisted of a sheet metal aluminum cylinder, 12 inches in height, which was mounted approximately 3 inches above the bus interface.


SPURIOUS TORQUE (IN.-LB)
80
70
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1.0
1.2
SEPARATION TIME (SEC)
S11291

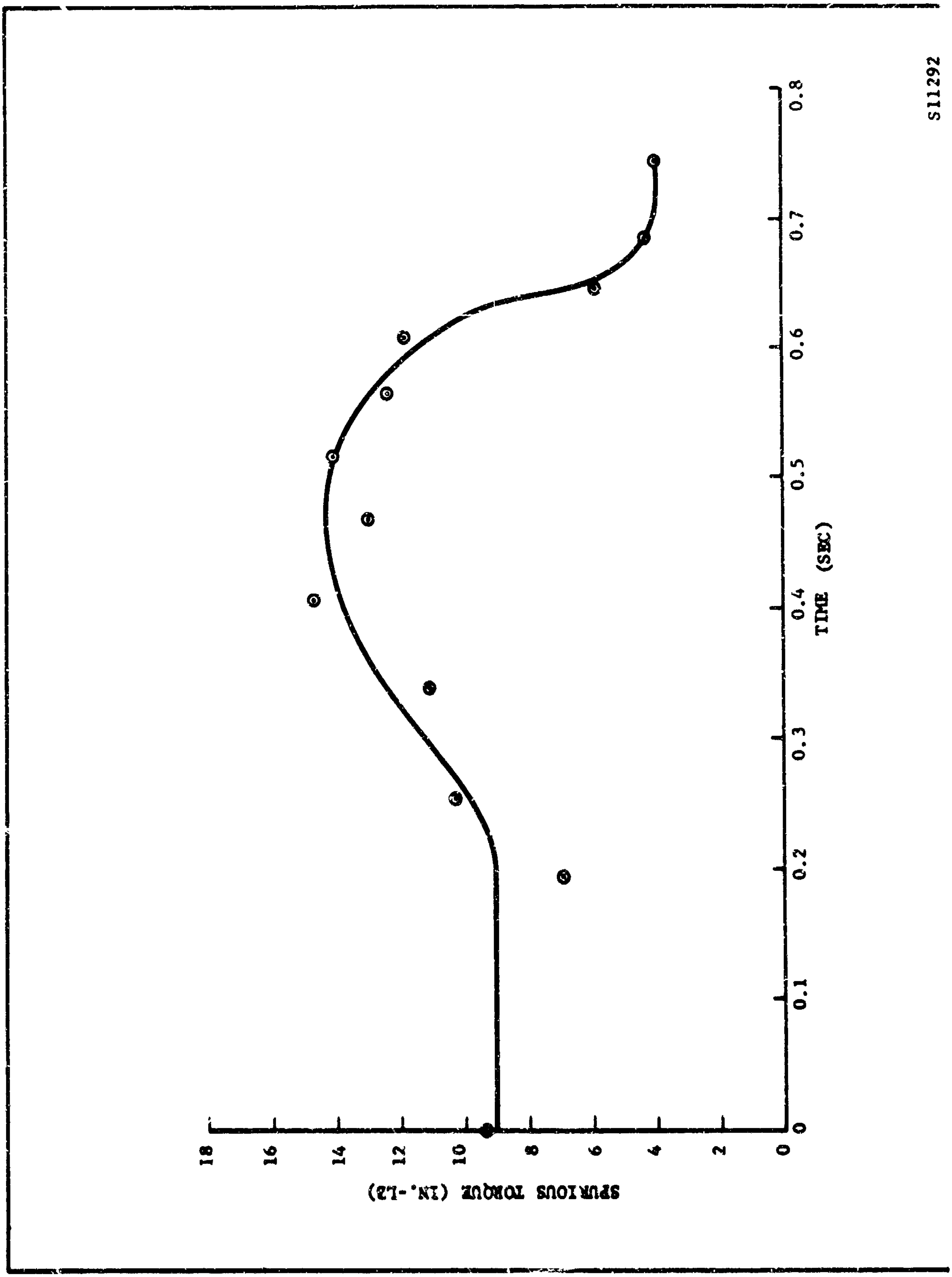
A polar plot of the spurious torque vector (with separation angle as a parameter) for a 0- to 21-inch separation distance made evident what appeared to be a systematic error in the data points. The phase of the vector, although random, was confined to a single quadrant. The indicated spurious torque appeared to be the sum of two vectors: (1) a very large systematic component, attributable to fixture error and windage which conceivably varied with separation distance; and (2) a relatively small component representing the effects of gas dynamics. Thus to evaluate the effect of gas dynamics, it became necessary to first determine the systematic error of measurement which existed at each point of separation. The vector difference between this latter quantity and that recorded represented the effects of gas dynamics.

To evaluate the systematic error it became necessary to gather dynamic separation data over a range of separation angles covering 360 degrees rather than only 120 degrees. The mean (for all separation angles) of the indicated spurious torque vector as a particular separation distance represents the systematic error of measurement irrespective of whether the gas dynamic portion of the measured torque is bus fixed or uniformly random.

The data with and without the symmetrical vent were treated in this manner. For each separation distance the mean (for separation angles 0 to 360 degrees) of the spurious torque components was computed, and the residuals, representing the magnitude of the orthogonal components of gas dynamic torque, were evaluated. Polar plots of these data again indicated no correlation of phase with separation angle, i.e., the phase appeared to be a uniformly distributed random phenomena; neither space or body fixed. Again, however, the absolute magnitude versus time shows as systematic variation.

The mean magnitude (considering all separation angles) of the spurious torque versus separation time with the symmetrical vent in position is shown in Figure 17. The spurious torque is approximately constant at one foot pound from 0 to 14 inches; thereafter the effects of gas dynamics rapidly diminish and the spurious torque assumes a value equal to the inherent motor unbalance.

The mean values of spurious torque were cross plotted as a function of capsule angle, using all values from 0 to 21 inches separation at each angle. This is shown in Figure 18. The function is sinusoidal in nature with a range of 6 to 16 in.-lb; peaks occur every 120 degrees of separation angle. With the exception of a phase shift, there were similar results found for the case without the symmetrical vent. It was on this basis that a separation angle of 0 degree was selected for the first live motor firing (No. 248) on the gas dynamic fixture.



S11292
TIME (SEC)
SPURIOUS TORQUE (IN.-LB)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
2
4
6
8
10
12
14
16
18

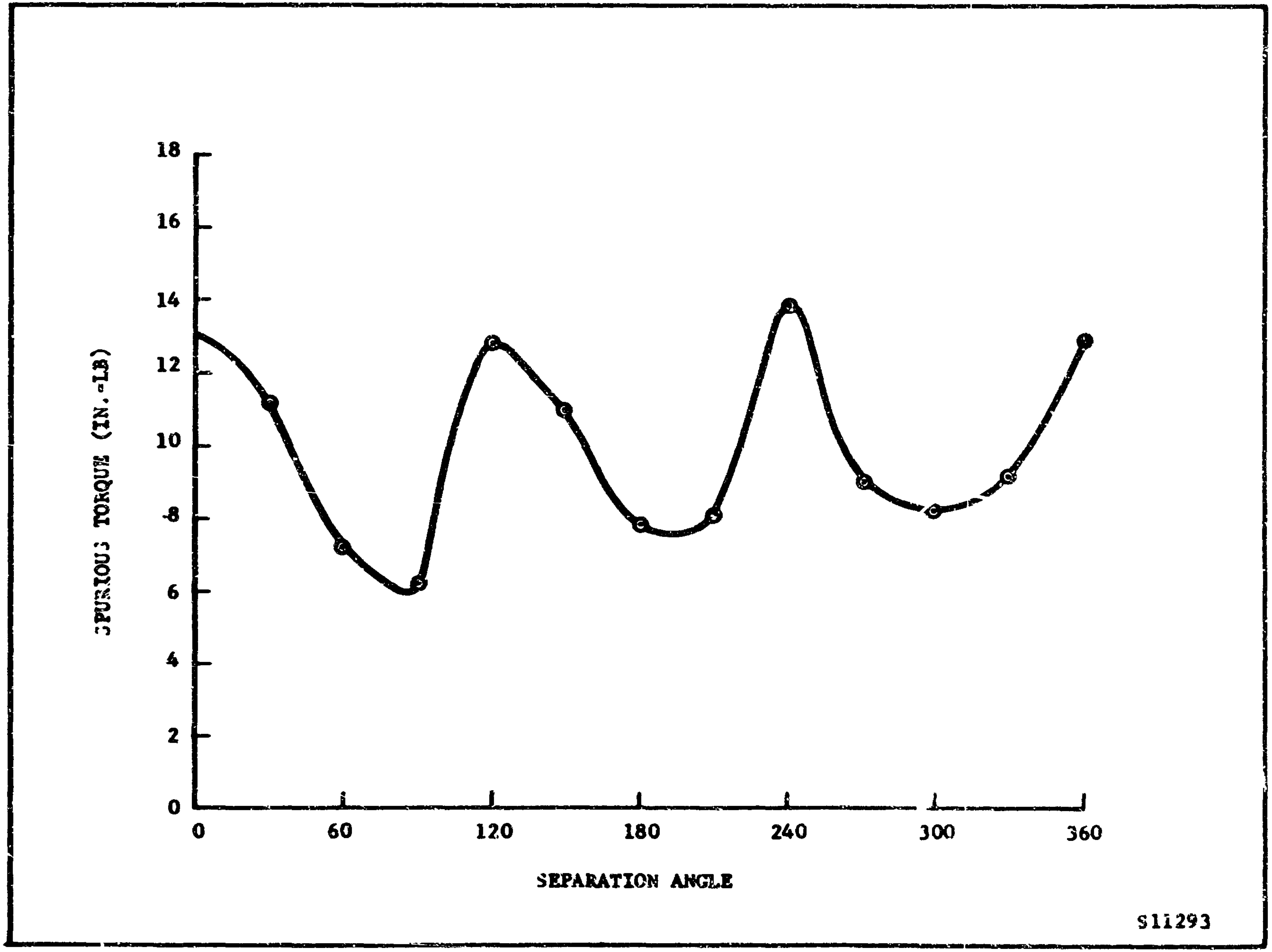


FIGURE 18. MEAN SPURIOUS TORQUE COLD FLOW GAS DYNAMIC FIXTURE
RUNS 639-651 (CORRECTED) WITH SYMMETRICAL VENT

Figure 19 presents pressure traces typical of those obtained during the foregoing cold flow tests. Typically there was a large (0.25 psi) pressure build-up inside of the support structure during the first 0.2 seconds (1 inch) of separation which rapidly diminished to between 0.06 and 0.08 psi for the remainder of the run. In each case the direction of the differential pressure across the retromotor nozzle was found to correspond with the phase of the spurious torque vector of the spurious torque vector.

7.4 MOTOR FIRING TESTS

A total of four firings were made on the gas dynamic fixture. In Section 6 of this report is included a discussion of the tip-off characteristics. The following description gives additional details of the system operation.

Run No. 248, March 16, 1962

(1) Test Configuration

(a) Spin Motor S/N L-308

(b) Radiation Shield 802120 A (w/o black cover)

(c) Symmetrical Vent 800112 A (Plastic part w/o reinforcement)

(d) Bus angle 0 degree - did not rotate during run

(e) Fired in closed position - separate at normal axial acceleration

(f) Fired at pressure altitude of 103,000 feet.

(2) Test Results

The symmetrical vent was severely damaged. It apparently buckled outward in the lower third (above the heavy section) in the area of impingement of the spin motor exhaust. The upper edge buckled in with a fluttering action and contacted the retronozzle in at least nine places. Contact areas were spaced about 120 degrees around the nozzle, approximately in line with the spin motor nozzles, and at separation distances from 8 to 14 inches. The points of contact can be seen clearly at one nozzle in Figure 20. As a result, the tip-off data were invalid.

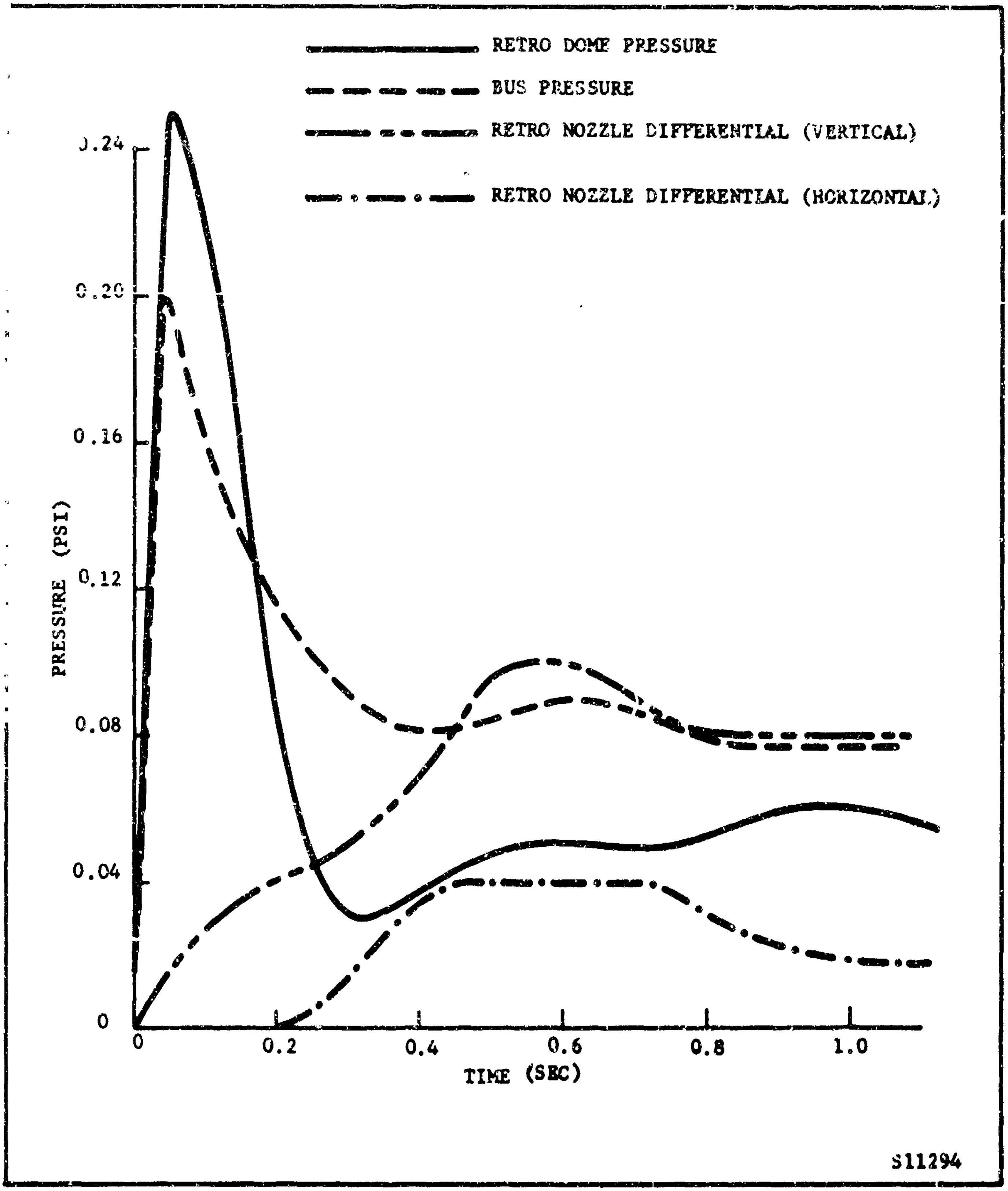


FIGURE 19. TYPICAL PRESSURE TRANSIENTS COLD FLOW - RUN 639

FIGURE 20. SYMMETRICAL VENT POINTS OF CONTACT

The radiation shield showed only superficial heat damage. A symmetrical vent modification was initiated as a result of this test.

Run No. 254, March 26, 1962

(1) Test Configuration

(a) Spin Motor S/N L-314

(b) Radiation Shield 802120 A (w/o black cover)

(c) No symmetrical vent

(d) Bus rotated at constant angular velocity of about 0.5 rad/sec.

(e) Fired in closed position with normal axial accelerations

(f) Fired at pressure altitude of 102,000 feet

(2) Test Results

The radiation shield was severely damaged. It was completely blown away on one side except for a narrow portion in the attaching are . The opposite side was billowed forward about 6 inches over the end of the motor support structure. The retronozzle marking indicated extensive radiation shield contact over the lower 12 inches. This is shown clearly in Figure 21.

Run No. 262, April 7, 1962

(1) Test Configuration

(a) Spin Motor S/N L-304

(b) Radiation Shield 800120 B (w/black cover)

(c) Symmetrical Vent 800143 (w/aluminum reinforcement)

(d) Spin Restraint 800135

(e) Bus angular position 180 degrees; did not rotate during run


S71296

(f) Fired in closed position, with normal axial accelerations

(g) Fired a pressure altitude of 105,000 feet.

(2) Test Results

The symmetrical vent and radiation shield showed superficial damage. There were no indications of contact with the retro simulator.

During the first 100 msec, there was indication of high tip off torque (~10 ft-lb). It was subsequently determined that this was caused by deflection of the bus simulator due to internal gas pressure. The amount of deflection was estimated from cold flow, and the corresponding tip-off moment subtracted out of the data for tip-off analysis.

The spin restraint apparently performed satisfactorily. In spite of direct exhaust blast on the attaching arms and springs, it returned to zero after the firing, with the spring constant unchanged. There was heavy deposit of exhaust residue on the exposed spring leaves. The set-up after firing is shown in Figure 22.

Run No. 265, April 11, 1962

(1) Test Configuration

(a) Spin Motor S/N L-312

(b) Radiation shield and symmetrical vent used from previous firing (Run No. 262).

(c) Spin Restraint 800135 - modified. The teflon shoes were removed from the restraint, and one lug was ground down to allow clearance for the bus deflection.

(d) Bus angular position 180 degrees; did not rotate during firing

(e) Fired in closed position, with normal axial accelerations

(f) Fired at pressured altitude of 105,000 feet.


S11297

(2) Test Results

No change in the condition of the heat shield or symmetrical vent could be observed. Performance of the entire system appeared to be satisfactory.

With the spin restraint relieved, the tip-off torques read directly as "no restraint" torques. The tip-off load caused by the spin restraint was computed from the measured deflection of the restraint and superimposed on the recorded torques. The results were analyzed both with and without restraint, and are tabulated in the summary.

The temperature of the exhaust gases was measured at various places in the bus and on the capsule. The data for several locations, with and without the symmetrical vent are shown in Figure 23.

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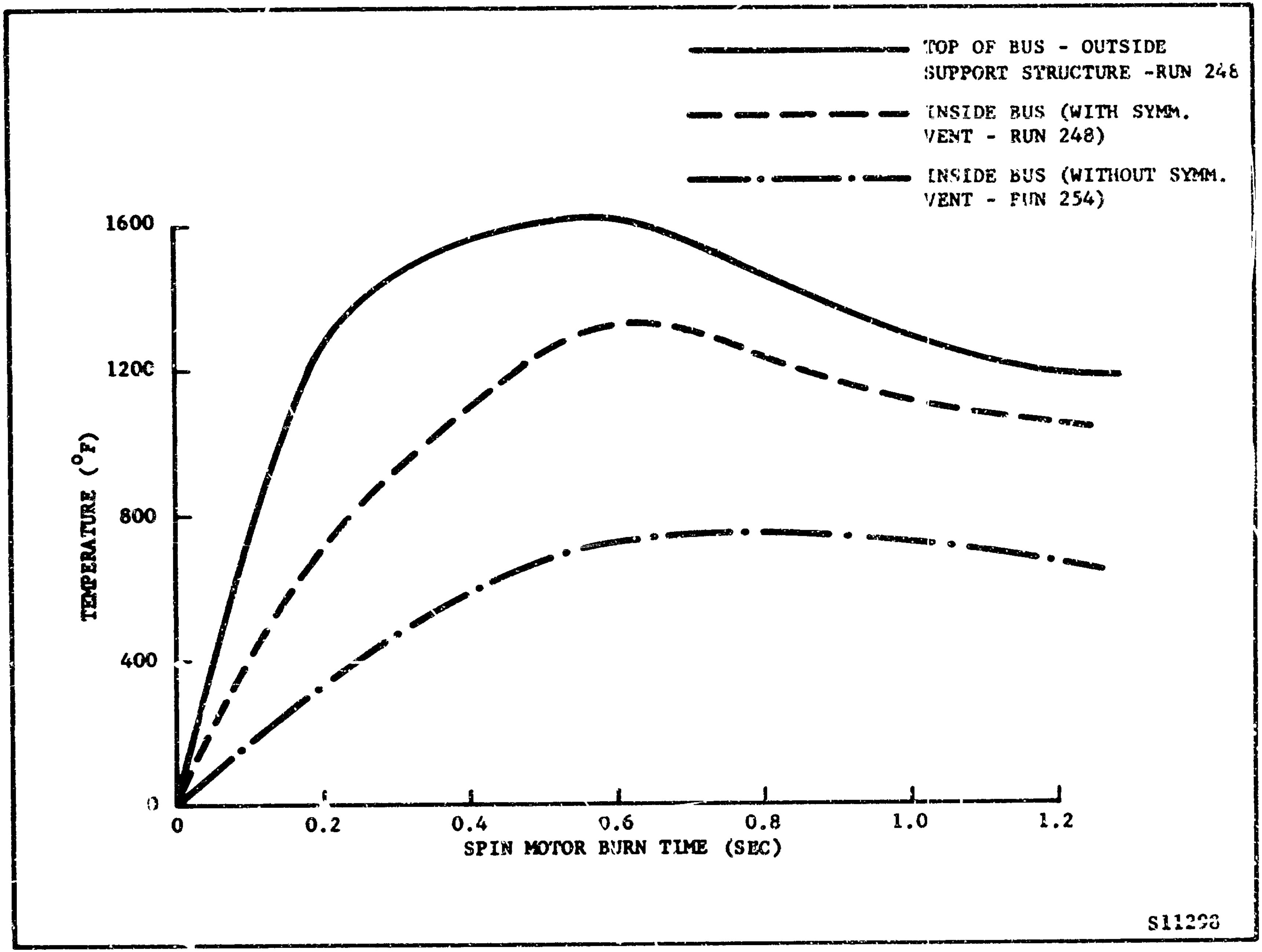
TOP OF BUS - OUTSIDE SUPPORT STRUCTURE -RUN 248
INSIDE BUS (WITH SYMM. VENT - RUN 248)
INSIDE BUS (WITHOUT SYMM. VENT - RUN 254)
1600
1200
800
400
0
TEMPERATURE (°F)
0
0.2
0.4
0.6
0.8
1.0
1.2
SPIN MOTOR BURN TIME (SEC)
S11298

SECTION 8

SURVEILLANCE FIRING OF SPIN MOTOR

To check the aging characteristics of the spin motor assembly, a flight type motor was stored for about 90 days before firing. This assembly consisted of the following:

Case S/N	L-60
Manifold S/N	L-110
Ignitor S/N	L-34
Assembly Date	5-14-62

The components and assembly procedures were in accordance with flight specifications in all respects, except that the manifold was rejected for out-of-tolerance spurious torque after cold flow balancing. The motor was assembled at a relatively humidity of 50% - the upper limit of the specifications.

The motor was fired on August 17, 1962, after 72 hours at a vacuum of about 12 μ. The nozzle caps were removed for the vacuum soak. The motor was fired at atmospheric pressure; the data listed below were converted to vacuum for comparison with previous qualification test data.

Parameter	Qualification Data Min	Qualification Data Max	Qualification Data Avg	Surveillance Round
Burn Time to 5% (sec)	1.10	1.19	1.14	1.10
Specific Impulse (sec)	204	210	208	210
Capsule Roll Rate	31.89	33.75	32.79	32.90

The ignition delay has not been tabulated as a line item, but it is consistent with previous firings.

In summary, the surveillance firing appeared completely typical in all respects.